Advanced strategies for the sustainable asset management of drinking water pipelines and networks

Christian Sorge, Angelika Becker
IWW Water Centre, Mülheim an der Ruhr/ Biebesheim am Rhein, Germany

*Corresponding Author: e-mail: c.sorge@iww-online.de

1. Abstract and Introduction

Operation and maintenance of water supply systems are major tasks for water utilities. To ensure an adequate water supply quality, requirements on asset condition and effective maintenance will further increase on the national and the international level. New holistic approaches for operational processes and maintenance strategies by evaluating results of asset condition assessment, inspection, material testing and leakage detection are available by now. Proven and tested concepts of condition assessment, structural re-design and reliability assessment of pipelines, partly based on corrosion data, will be presented. Main result of these concepts is the remaining technical operating life of single pipelines or a whole network to improve a sustainable asset management in water utilities.

2. Common assessment approaches

In most cases, failure records and asset data stock are used to assess pipeline or network conditions or to predict their remaining service life (Alegre & Coehlo 2013, Kleiner & Rajani 2001). Some probabilistic methods are available to support that, as survival models (e.g. Kaplan-Meyer-estimator in combination with Weibull-functions or the "Herz"-distribution), or the determination of failure rates in combination with trend functions (Herz 2002). If the data base does not contain valid information (for instance missing attributes, no information about the historic renewing activities of the water utilities, incorrect allocation or interpretation of failure data[1]…), the results of the mentioned methods are first estimations but not more than that. Often failure data are available in the water utilities for only 1 – 5 % of the network length - the predominant part of the network is not noticeable. So failure data cannot be representative for the whole network and there are some challenges to predict the remaining service life for this part.

[1] To determine the "real" failure rate, one has to use all real failure data from all pipelines of a selected material group (cohorts, e.g. grey cast iron from rotating spun), which have the same age, and the actual length of the related pipelines at this age. It is an advantage to have a well-kept historic data stock with information about already renewed pipelines. However, only a small part of the failure data stock from a water utility is useful for this type of failure analyses (1 – 10%) and indicates an actual trend or deterioration process – the bigger part of failure data is not really usable.

Pipeline inspection methods and material testing (non-destructive and destructive methods) can provide very detailed information about the condition of selected parts of pipelines or networks. In combination with structural mechanics and load design or corrosion diagnostics, it is possible to determine the remaining service life of these parts (Sorge 2007).

Methods for leakage detection aren't applicable to predict the remaining service life of pipelines or networks. But in combination with failure records and by analyzing long-term trends of leakage rates, it could be possible to get indicators to estimate the condition.

3. New assessment approaches

3.1 Technical condition assessment

IWW has gained much experience in the assessment of the technical condition of pipe samples. The results from tests on more than 350 pipe samples show that there is no relation between the age and the technical condition (material: grey cast iron, ductile iron, steel) – see figure 1. This means that the information "age" is not useful for further analyses or a condition assessment (for metallic pipes and asbestos cement pipes). But it seems to be an important parameter to assess the condition of plastic pipes (PVC and PE), when taking into consideration the decreasing strength of plastic pipes over time (Gaugler & Kocks 2010).

One can close with these results:

1. Metallic and asbestos cement pipes - no decreasing pipe strength conditions over time but decreasing pipe wall thickness, due to corrosion processes
2. Plastic pipes - decreasing pipe strength conditions over time, caused by embrittlement and slow crack propagation and other factors but no decreasing wall thickness.

The results show that, with a very high probability, the wear and tear reserves of metal pipes decrease with increasing age. The following parameters are necessary to determine the remaining service life (remaining time to perforations at steel or ductile iron pipes or remaining time to breaks at grey cast iron pipes):

- remaining wall thickness,
- corrosion rates related to environment conditions or water quality and
- the load-bearing capacity of the pipe (incl. bedding conditions and loads) as well as pipe strength as tensile strength or elastic modulus (see figure 3).

This is also the core of the IWW concept for technical condition assessment of metallic pipelines.

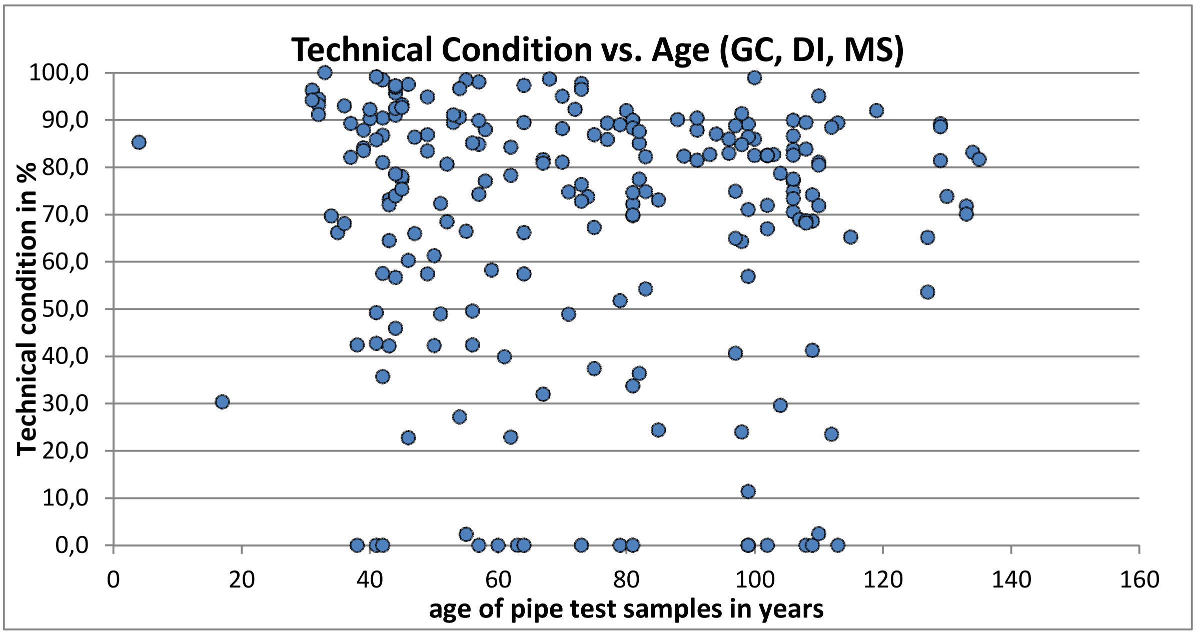

Figure 1: Results from the assessment of metallic pipe test samples at IWW. A condition of 100% means, that there are no parts of weakness in the pipe wall.

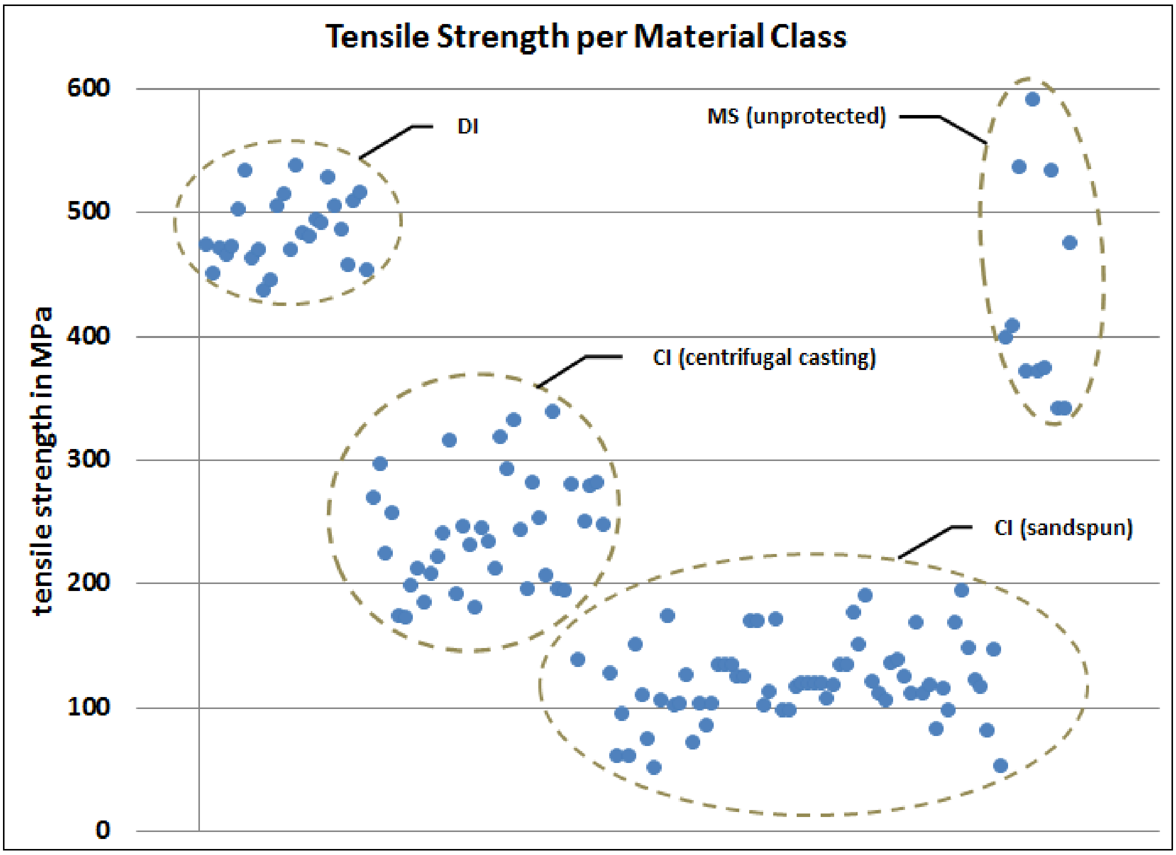

Figure 2: Tensile strength per material class (DI = ductile iron, CI = cast iron, MS = mild steel)

3.2 Reliability Assessment

The remaining service life of a pipeline is a function of its durability or stability in combination with failures. In engineering, the stability of a technical component (like a pipeline) is the ratio between loads and load-bearing capacity (plus a safety factor). There are proven models and algorithms to determine the remaining load bearing capacity of pipelines or to calculate present safety factors (Watkins & Anderson 2000). The smaller the safety factor, the higher the probability of breaks, cracks or exorbitant deformation of the pipe - and the remaining service life is decreasing.

Based on reliability assessment methods for buildings and other constructions (Quast 2002), IWW has developed a method to determine the failure probability, based on safety factors for pipelines and deduced from reliability indices. And it is also possible to determine the time frame, if a fixed reliability index is undershot (see figure 3). This could be set as the technical service life for a pipeline, if the failure probability for a certain number of breaks per length is one, for instance. It is possible to determine these values for each pipeline segment of a whole network – independent of the real technical conditions at first. In addition, the simulation of deterioration processes by pitting corrosion and its impact on the load-bearing capacity will be enabled, if further data about the pipe strength, the diameter, wall thickness, environmental and bedding conditions and loads are available. But these data are seldom available in water utilities, in the light of experience. For instance, there seems to be a high uncertainty to estimate environmental and bedding conditions (at a first glimpse).[2]

Within a research project, funded by the RWE Deutschland AG, IWW has identified the most important factors on the stability of a pipeline by structural load design and sensitivity analyses – (see the example in table 1). Efforts or measures to name the factors could be reduced to the most important ones – depending on the pipe material classes. Loads (as inner pressure or traffic loads), for instance, can be estimated relatively easy and confident.

Related to some pipe material classes (e.g. grey cast iron from sand spun), the pipe strength conditions vary only a little or are better than required. Tests on pipe samples show: actual pipe diameter and wall thickness vary only a little from specifications in related technical rules – if there were no corrosion attacks (for metal and asbestos cement pipes, and it is expected also for plastic pipes). It seems that such geometric attributes have a significant statistical distribution. Thus, statistical analyses methods could be used for further estimations.

[2] The DVGW German Society for Gas and Water prepares a fact sheet about Technical Condition Assessment of metallic pipelines and associated testing tools/methods - together with experts from water/gas utilities, companies and institutes.

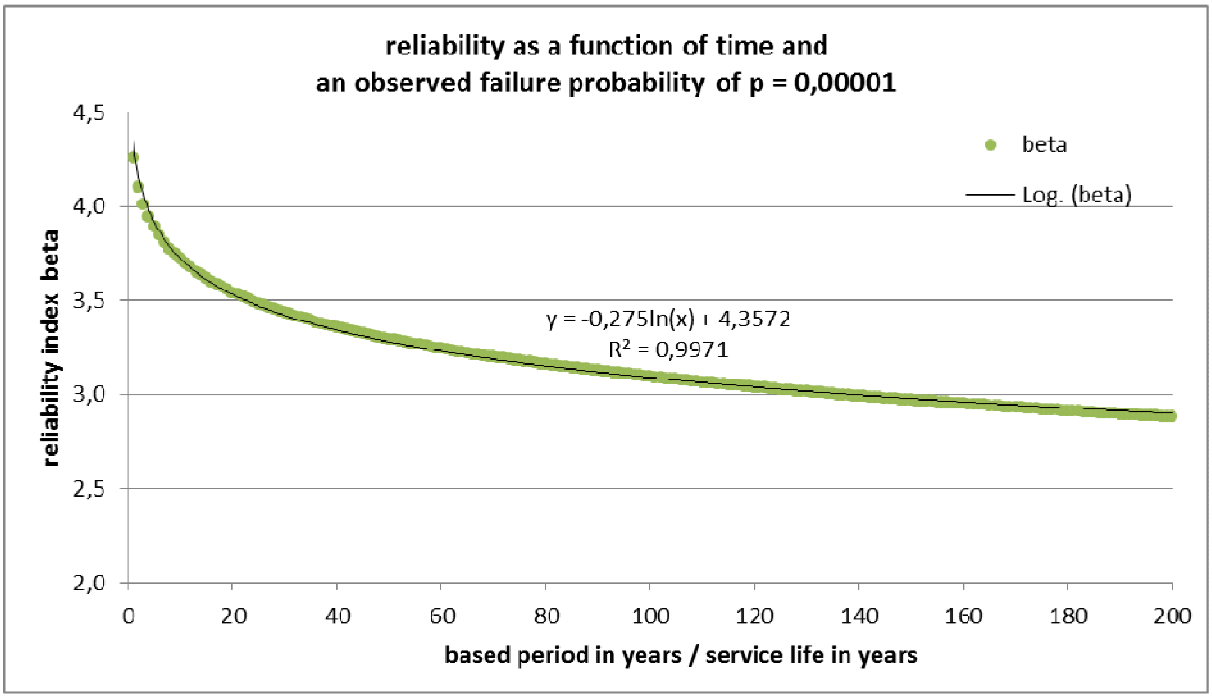

Figure 3: Graph of the reliability index beta as a function of time and an observed failure probability. The acceptable reliability index for a pipeline segment (length = 6m; acceptable failure rate = 0.1 failure per km and year) was set as beta = 3.244 (one year) with a service life of 60 years, as a consequence.

Table 1: important (unfavourable) factors on pipe stability (grey cast iron from rotating spun)

	unfavourable factors	almost irrelevant factors[3]
Rank 1	(high) traffic loads	elastic modulus
Rank 2	loose bedding zone (uncompacted), compacted cover zone	cover depth
Rank 3	wide trench while installation	trench lining
Rank 4	small pipe seat in the bedding (60°)	inner p ressure
Rank 5	small wall thickness	-
Rank 6	wider diameter	-
Rang 7	low tensile strength	-

Especially higher danger for breaks in case of poor bedding conditions: diameter DN 80 to DN 150

4. Reliability-based and risk-based maintenance strategies

Information about current and coming failure rates, leakage rates, average expected life span and maintenance costs are used to create so called condition-based maintenance strategies. Uncertainties, due to poor failure records or data stock of the

[3] In relation to the most factors

network, re-emerge in the results of such strategies (in annual renewal plans or investment plans, for instance).

The mentioned reliability assessment method in combination with destructive or non-destructive inspection methods (primarily on suspicious pipeline or network segments) could be appropriate to reduce or avoid such uncertainties. Thus, the validity of results will increase.

To gain the practicality of a maintenance strategy, further aspects in regard to failure or damage oncost should be considered. Different types of failure lead to different efforts (and costs) for repair/renewal. Breaks and leakages on pipelines can cause damage in the underground, to other pipelines or on other infrastructures (e.g. flooded basement).

Such aspects are considered in so called risk-based maintenance strategies (Sorge *et al.* 2013). The associated assessment methods include technical and economic aspects like damages and costs, caused by pipe failures, third party property damage as well as damages to intangible assets (loss of company reputation).

5. Conclusions

Conventional approaches for compiling maintenance strategies for pipelines or networks are almost solely based on the account of the pipe age and failure rates. Such approaches are only suitable to a limited extent, as significant influences on the likelihood of failures and structural mechanics of pipelines are inadequately considered, for instance. The concept of a reliability based assessment of pipelines and networks allows creating maintenance strategies, even if there are no failure records or trends at failure rates. The reliability based approach considered and assesses the actual failure or “aging” mechanisms of pipelines (corrosion, embrittlement, strength, weakness, loads and load capacity). Thus, the validity of assessment results and maintenance plans may be increased. By extension of such approaches to a risk-based assessment, there is also an economic way to find or choose adequate pipeline segments for further assessment methods like non-destructive inspections or technical condition assessment on pipe samples.

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